Oblique Deposition to Induce Magnetic

Anisotropy for MRAM Cells

5   FIELD OF THE INVENTION

This invention relates to semiconductor memory devices

and, more particularly, the present invention relates to

devices that utilize magnetic thin films.

10   BACKGROUND OF THE INVENTION

Memory devices are an extremely important component in

electronic systems. The three most important commercial

high-density memory technologies are SRAM, DRAM, and FLASH.

Each of these memory devices uses an electronic charge to

15   store information and each has its own advantages. For

example, SRAM has fast read and write speeds, but it is

volatile and requires a large cell area. DRAM has a high

memory density, but it is also volatile and requires a

refresh of the storage capacitor every few milliseconds.

20   This refresh requirement increases the complexity of the

control electronics.

FLASH is the major nonvolatile memory device in use

today. Typical FLASH memory devices use charges trapped in

a floating oxide layer to store information. Drawbacks to

25   FLASH include high voltage requirements and slow program

and erase times. Also, FLASH memory has a poor write

endurance of about 10^4-10^6 cycles before memory failure. In

addition, to maintain reasonable data retention, the
thickness of the gate oxide has to stay above the threshold
that allows electron tunneling. This thickness requirement
severely restricts the scaling trends of FLASH memory.

5   To overcome these shortcomings, magnetic memory
devices are being evaluated. One such device is
magnetoresistive random access memory (hereinafter referred
to as "MRAM"). MRAM has the potential to have a speed
performance similar to DRAM. To be commercially viable,

10   however, MRAM should have comparable memory density to
current memory technologies, be scalable for future
generations, operate at low voltages, have low power
consumption, and have competitive read/write speeds.

        For an MRAM device, the stability of the memory state,

15   the repeatability of the read/write cycles, and the power
consumption are some of the more important aspects of its
design characteristics. A memory state in MRAM is not
maintained by power, but rather by the direction of a
magnetic moment vector. In typical MRAM devices, storing

20   data is accomplished by applying magnetic fields and
causing a magnetic material in an MRAM cell to be
magnetized into either of two possible memory states.
Recalling data is accomplished by sensing the resistive
state of the cell which depends on the magnetic state. The

25   magnetic fields are created by passing currents through
strip lines external to the magnetic structure or through
the magnetic structures themselves.

For standard MRAM devices, the switching field H_{sw} is proportional to the total anisotropy H_{k_total} of the bit, which can include contributions from the device shape and material composition. Most MRAM devices rely on a bit

5 shape having an aspect ratio greater than unity to create a shape anisotropy H_{k_shape} that provides the switching field H_{sw}.

However, there are several drawbacks to relying on H_{k_shape} to provide H_{sw}. First, H_{k_shape} increases as the bit

10 dimension shrinks so that H_{sw} increases for a given shape and film thickness. A bit with larger H_{sw} requires more current to switch. Second, variations in H_{sw} will occur due to variations in bit shape from lithographic patterning and etching. These variations will increase as the bit size

15 shrinks due to the finite resolution of optical lithography and etch processes. Variations in H_{sw} translate into a smaller operating window for programming of the bits and are therefore undesirable. Third, the range over which the magnitude of H_{k_shape} can be varied is limited. Only certain

20 bit shapes produce reliable switching and although varying the thickness of the film will vary H_{k_shape}, there is a maximum bit thickness above which the bit switching quality degrades due to domain formation.

Other MRAM devices rely on anisotropy from pair

25 ordering of like atoms to provide all or part of H_{k_total}. For example, if a nickel iron (NiFe) film is deposited in a magnetic field, a small percentage of the iron (Fe) and

nickel (Ni) atoms pair with like atoms and form chains
parallel to the magnetic field, providing a pair anisotropy
of approximately 5 Oe substantially parallel to the
magnetic field direction.

5   Pair ordering anisotropy H_{k_pair} has the advantage of
being substantially independent of bit shape and is
relatively unchanged as the bit size decreases. However,
the magnitude and direction of H_{k_pair} can drift with
temperature. This temperature drift substantially results
10   from thermal diffusion of the atom pairs. In addition, the
magnitude of H_{k_pair} is predominately fixed for a particular
magnetic material which limits the range of H_{sw}.

       Based on the limitations of shape and pair anisotropy
discussed above, it is clear that a need exists to adjust
15   the switching magnetic field H_{sw} using a magnetic anisotropy
which is adjustable over a wide range, does not
substantially depend on bit shape, and is thermally stable.
Accordingly, it is an object of the present invention to
provide a new and improved method of fabricating a
20   magnetoresistive random access memory device.

               BRIEF DESCRIPTION OF THE DRAWINGS
       The foregoing and further and more specific objects
and advantages of the instant invention will become readily
25   apparent to those skilled in the art from the following
detailed description of a preferred embodiment thereof
taken in conjunction with the following drawings:

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FIG. 1 is a sectional view of a magnetoresistive random access memory device in accordance with the present invention;

FIG. 2 is a simplified plan view of a magnetoresistive
5 random access memory device in accordance with the present invention;

FIG. 3 is an oblique view of a substrate with a material layer being deposited at a nonzero deposition angle;

10 FIG. 4 is a graph illustrating a magnitude of an induced anisotropy verses a deposition angle for a 25 nm nickel iron (NiFe) layer;

FIG. 5 is a graph illustrating a magnitude of an induced anisotropy verses a deposition angle for a 25 nm
15 nickel iron (NiFe) layer deposited on a 25 nm tantalum (Ta) layer;

FIG. 6 is a top view a physical vapor deposition system used to deposit material layers in accordance with the present invention;

20 FIG. 7 is a side view of the physical vapor deposition system used to deposit material layers in accordance with the present invention; and

FIG. 8 is a graph illustrating a normalized magnetic anisotropy H_k verses anneal temperature for a bulk nickel
25 iron cobalt (NiFeCo) film deposited on a tantalum (Ta) layer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Turn now to FIG. 1, which illustrates a simplified

sectional view of an MRAM array 3 in accordance with the

present invention. In this illustration, only a single

5   MRAM device 10 is shown, but it will be understood that

MRAM array 3 generally includes a number of MRAM devices.

However, we are showing only one such device for simplicity

and ease of discussion to illustrate a method of depositing

a material layer at an oblique angle to induce a magnetic

10   anisotropy. Also, while MRAM devices are discussed and

magnetic tunnel junction (MTJ) devices specifically, it

will be understood that other magnetoelectronic devices

(e.g. GMR devices, magnetic sensors, etc.) can be produced

using similar techniques.

15   In a preferred embodiment, MRAM device 10 is

sandwiched therebetween a bit line 20 and a digit line 30.

Bit line 20 and digit line 30 include conductive material

such that a current can be passed therethrough. In this

illustration, bit line 20 is positioned on a surface 36 of

20   MRAM device 10 and digit line 30 is positioned on a surface

34 of MRAM device 10 wherein digit line 30 is oriented

approximately at a 90° angle relative to bit line 20 (See

FIG. 2). However, it will be understood that the

positioning of bit line 20 and digit line 30 is for

25   illustrative purposes only wherein many other

configurations are possible.

Turn now to FIG. 2 which illustrates a simplified plan view of MRAM array 3 in accordance with the present invention. To simplify the description of MRAM device 10, all directions will be referenced to an x- and y-coordinate

5   system 100 as shown. The purpose of bit line 20 and digit line 30 is to create a magnetic field within MRAM device 10. A positive bit current (i.e. a bit current flowing in the positive x-direction), I_B, will produce a circumferential bit magnetic field, H_B, and a positive

10   digit current (i.e. a digit current flowing in the positive y-direction), I_D, will produce a circumferential digit magnetic field, H_D.

Since bit line 20 is above MRAM device 10, in the plane of the element, H_B will be applied to MRAM device 10

15   in the positive y-direction for positive I_B. Similarly, since digit line 30 is below MRAM device 10, in the plane of the element, H_D will be applied to MRAM device 10 in the positive x-direction for positive I_D. The behavior of a current produced magnetic field is well known to those

20   skilled in the art and will not be elaborated upon further here.

Turning back to FIG. 1, MRAM device 10 includes a tunneling barrier 16 sandwiched therebetween a magnetic region 15 and a magnetic region 17, wherein a portion of

25   MRAM device 10 is deposited at a nonzero deposition angle, θ, as will be discussed separately with FIG. 3. In the preferred embodiment, tunneling barrier 16 can include an

electrically insulating material, such as aluminum oxide,
or the like to form a tunneling junction.

Also in the preferred embodiment, magnetic region 15
includes a tri-layer structure 18, which has an anti-

5   ferromagnetic coupling spacer layer 65 sandwiched
therebetween a ferromagnetic layer 45 and a ferromagnetic
layer 55. Further, in the preferred embodiment, magnetic
region 17 has a tri-layer structure 19, which includes an
anti-ferromagnetic coupling spacer layer 66 sandwiched

10   therebetween a ferromagnetic layer 46 and a ferromagnetic
layer 56.

It will be understood that magnetic regions 15 and 17
can include N ferromagnetic layers wherein N is a whole
number greater than or equal to two. However, in the

15   preferred embodiment, N is equal to two so that magnetic
regions 15 and 17 each include one tri-layer structure 18
and 19, respectively. It should be understood that tri-
layer structures are often referred to as synthetic anti-
ferromagnetic (hereinafter referred to as "SAF")

20   structures.

Also, it will be understood that magnetic regions 15
and 17 can include SAF layer material structures other than
tri-layer structures and the use of tri-layer structures in
this embodiment is for illustrative purposes only. For

25   example, one such SAF layer material structure could
include a five-layer stack of a ferromagnetic layer/ anti-
ferromagnetic coupling spacer layer/ ferromagnetic

layer/anti-ferromagnetic coupling spacer layer/

ferromagnetic layer structure. Also, magnetic regions 15

and 17 can include other magnetic material structures which

produce a magnetic moment vector, such as a single magnetic

5   layer.

Generally, anti-ferromagnetic coupling spacer layers

65 and 66 include at least one of the elements ruthenium

(Ru), rhenium (Re), osmium (Os), titanium (Ti), chromium

(Cr), rhodium (Rh), platinum (Pt), copper (Cu), palladium

10   (Pd), or alloys thereof. Further, ferromagnetic layers 45,

55, 46, and 56 generally include at least one of elements

nickel (Ni), iron (Fe), cobalt (Co), or alloys thereof.

In the preferred embodiment, ferromagnetic layers 45 and 55

each have a magnetic moment vector 57 and 53, respectively,

15   that are usually held anti-parallel by the coupling of

anti-ferromagnetic coupling spacer layer 65. Further,

ferromagnetic layers 46 and 56 each have a magnetic moment

vector 47 and 43, respectively, that are usually held anti-

parallel by the coupling of anti-ferromagnetic coupling

20   spacer layer 66. Also, magnetic region 15 has a resultant

magnetic moment vector 40 and magnetic region 17 has a

resultant magnetic moment vector 50.

It will be understood that resultant magnetic moment

vector 40 is the vector sum of magnetic moment vectors 53

25   and 57 and resultant magnetic moment vector 50 is the

vector sum of magnetic moment vectors 43 and 47. In the

case of a balanced magnetic moment between layers 45 and

55, resultant magnetic moment vector 40 is approximately zero. However, the magnetoresistance is still determined by the magnetic moment vectors (i.e. magnetic moment vectors 47 and 53) adjacent to tunneling barrier 16.

5   In the preferred embodiment, resultant magnetic moment vectors 40 and 50 are oriented substantially along an anisotropy easy axis 12 (See FIG. 2) in a preferred direction that is at an angle, preferably 45°, from bit line 20 and digit line 30 (See FIG. 2). Easy axis 12 is

10   also oriented approximately 90° from an anisotropy hard axis 14 (See FIG. 2). Further, magnetic region 15 is a free magnetic region, meaning that resultant magnetic moment vector 40 is free to rotate in the presence of an applied magnetic field. Magnetic region 17 is a pinned

15   magnetic region, meaning that resultant magnetic moment vector 50 is generally not free to rotate in the presence of an applied magnetic field and is used as a reference.

      In the preferred embodiment, resultant magnetic moment vector 50 is substantially pinned due to an anti-

20   ferromagnetic coupling between magnetic region 17 and an anti-ferromagnetic region 32 which includes a seed layer 31. It will be understood, however, that the formation of magnetic regions 15 and 17 as the free and pinned magnetic regions, respectively, is for illustrative purposes only

25   and that other configurations are possible. For example, magnetic region 15 could be formed as the pinned magnetic

region and magnetic region 17 could be formed as the free

magnetic region.

MRAM device 10 is capable of flowing a tunneling

current therethrough tunneling barrier 16. The tunneling

5   current substantially depends on a tunneling

magnetoresistance of MRAM device 10, which is governed by

the relative orientation of magnetic moment vectors 53 and

47 adjacent to tunneling barrier 16. If magnetic moment

vectors 53 and 47 are substantially parallel, then MRAM

10   device 10 has a low resistance and a voltage bias

therebetween bit line 20 and digit line 30 will create a

larger tunneling current through MRAM device 10. This

state is defined as a "1".

If magnetic moment vectors 53 and 47 are substantially

15   anti-parallel, then MRAM device 10 will have a high

resistance and an applied voltage bias therebetween bit

line 20 and digit line 30 will create a smaller current

therethrough MRAM device 10. This state is defined as a

"0".

20   It will be understood, however, that these definitions

are arbitrary and could be reversed, but are used in this

example for illustrative purposes. Thus, in typical

magnetoresistive memory, data storage is accomplished by

applying magnetic fields that cause the magnetic moment

25   vectors in the free ferromagnetic region to be orientated

in either one of parallel and anti-parallel directions

relative to the magnetic moment vector in the pinned

ferromagnetic region.

While anti-ferromagnetic coupling layer 65 is

illustrated between ferromagnetic layers 45 and 55 in tri-

5   layer structure 18, it will be understood that

ferromagnetic layers 45 and 55 could be anti-

ferromagnetically coupled through other means, such as

magnetic fields or other features. For example, when the

aspect ratio of an MRAM cell is reduced to five or less,

10   the ferromagnetic layers are substantially coupled anti-

parallel from magnetic flux closure.

In the preferred embodiment, MRAM device 10 has tri-layer

structures 18 and 19 that have a length/width ratio in a

range of one to five for a non-circular plan. We

15   illustrate a plan with an aspect ratio equal to two (See

FIG. 2). MRAM device 10 is elliptical in shape in the

preferred embodiment to minimize the contribution to

switching field variations from shape anisotropy and also

because it is easier to use photolithographic processing to

20   scale the device to smaller dimensions laterally. However,

it will be understood that MRAM device 10 can have other

shapes, such as circular, square, rectangular, diamond, or

the like, but is illustrated as being elliptical for

simplicity and improved performance.

25   Further, during fabrication of MRAM array 3, each

succeeding layer (i.e. 30, 31, 32, 56, etc.) is deposited

or otherwise formed in sequence and each MRAM device 10 may

be defined by selective deposition, photolithography

processing, etching, etc. in any of the techniques well

known to those skilled in the art.

As mentioned previously, a portion of MRAM device 10

5   is deposited at the nonzero deposition angle, θ, as shown

in FIG. 3 where a substrate 74 with a surface 76 is

illustrated. A material flux 72 is incident to surface 76

at the angle θ relative to a reference line 78 oriented

perpendicular to surface 76. Material flux 72 forms a

10   material region 80 positioned on surface 76. Material

region 80 typically has an induced uniaxial magnetic

anisotropy, H_{ki}, substantially oriented parallel, $H_{ki}(\parallel)$,

or perpendicular, $H_{ki}(\perp)$, to a plane of incidence and

parallel to surface 76 . The plane of incidence is defined

15   by reference line 78 and a reference line 79 oriented

parallel to material flux 72. Further, it will be

understood that material flux 72 can include magnetic or

non-magnetic materials. In the preferred embodiment, the

direction of the induced magnetic anisotropy of material

20   region 80 substantially depends on θ, as will be discussed

presently.

Atoms deposited by vapor deposition techniques such as

evaporation, physical vapor deposition, or ion-beam

deposition have a distribution of deposition angles that is

25   dependent on the details of the deposition process. The

deposition angle θ is defined as the average deposition

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angle for the flux of atoms that deposit on the wafer to

form the layer. To achieve an average angle of zero, the

atoms can be directly deposited at normal incidence or the

flux of atoms can have deposition angle θ and the wafer can

5   be rotated during the deposition to produce an average

angle of zero.

Turn now to FIG. 4 which illustrates a graph 90 of the

magnitude of the induced magnetic anisotropy, H_{ki}, verses θ

when material region 80 includes a 25 nm nickel-iron alloy

10   (NiFe) layer. In graph 90, circles designate $H_{ki}(\parallel)$ and

squares designate $H_{ki}(\perp)$, where parallel($\parallel$) and

perpendicular ($\perp$) refer to the anisotropy axis being

parallel or perpendicular to the plane of incidence of the

average deposition flux direction and in the plane of the

15   substrate. The magnitude of the induced magnetic anisotropy

increases with θ from approximately 5 Oe at θ equal to 20°

to approximately 70 Oe at θ equal to 60°. The direction of

the pair-ordering anisotropy is set by an applied magnetic

field during deposition, giving rise to a small $H_{ki}(\parallel)$ at θ

20   equal to 0°. For intermediate angles the induced

anisotropy is parallel and overcomes the small pair-

ordering anisotropy to result in a material with

significant $H_{ki}(\parallel)$. For the larger deposition angles the

induced anisotropy becomes perpendicular and adds

25   substantially to the pair-ordering anisotropy.

Turn now to FIG. 5 which illustrates a graph 92 of the

magnitude of the induced magnetic anisotropy verses θ for

the 25 nm nickel iron (NiFe) layer positioned on a 25 nm

tantalum (Ta) layer also deposited at angle θ. Plotted in

5   graph 92 is $H_{ki}(\perp)$ and $H_{ki}(\parallel)$ wherein the magnitude of the

induced magnetic anisotropy increases with θ as shown. As

mentioned previously, the magnitude of H_k varies over a

substantial range wherein the width of the range generally

increases with the number of layers deposited at an oblique

10   angle. In this example, H_{ki} varies over a range given

approximately by 5 Oe to 500 Oe when θ is varied from

approximately 20° to 60°, respectively, wherein the upper

limit of this range (i.e. 500 Oe) is substantially greater

than the upper limit (i.e. 70 Oe) for the 25 nm nickel iron

15   (NiFe) layer discussed in FIG. 4. Thus, from FIGS. 4 and

5, it is evident that H_{ki} can be varied over a wide range

for substantially the same material composition.

In the preferred embodiment, the origin of $H_{ki}(\parallel)$ and

$H_{ki}(\perp)$ for nickel iron (NiFe) films is substantially a

20   result of the oblique deposition angle inducing a surface

topography of a film that results in an induced anisotropy

H_{ki}. For a small θ, grains within the film become

substantially elongated parallel to the plane of incidence

due to the deposition velocity in a direction parallel to

25   the plane of incidence. This elongation produces a micro-

shape anisotropy parallel (i.e. $H_{ki}(\parallel)$) to the plane of

incidence. For a larger θ, self-shadowing from the surface

roughness produces a corrugation of the film surface

substantially perpendicular to the plane of incidence.

This produces an induced anisotropy substantially

5   perpendicular (i.e. $H_{ki}(\perp)$) to the plane of incidence. At

an intermediate θ, $H_{ki}(\perp)$ and $H_{ki}(\parallel)$ are substantially

comparable in magnitude and orthogonal in direction.

For orthogonal anisotropies, the net anisotropy has a

magnitude given by the difference between the two

10   anisotropies and a direction defined by the larger

anisotropy. Thus, the total anisotropy for the films in

FIG. 4 and FIG. 5 is approximately

$$H_{k\_total}(\theta) = H_{k\_pair} - H_{ki}(\parallel) + H_{ki}(\perp).$$
In FIG. 4, H_{k_pair} is deposited to be substantially

15   perpendicular to the plane of incidence. As θ increases,

$H_{ki}(\parallel)$ increases quickly so that H_{k_total} becomes negative.

As θ increases further, $H_{ki}(\perp)$ dominates and H_{k_total} again

becomes positive. The net result is that there are two

points where H_{k_total} is zero or quite small due to the

20   cancellation of the various anisotropies.

A similar trend is observed in FIG. 5, except that now

the magnitude of H_{ki} for a large θ is significantly

increased. This increase is caused by the surface

corrugation of the tantalum (Ta) layer so that $H_{ki}(\perp)$ is

25   even larger than for nickel-iron (NiFe) alone.

While nickel-iron (NiFe) films display both a $H_{ki}(\parallel)$

and $H_{ki}(\perp)$ as a function of θ, some materials do not

substantially display a significant $H_{ki}(\parallel)$ but rather only

display a significant $H_{ki}(\perp)$. It will be understood,

5   however, that in the preferred embodiment we discuss the

case of nickel-iron (NiFe) for illustrative purposes and

ease of discussion.

Turn now to FIG. 8 which illustrates an experimental

measurement of a normalized magnetic anisotropy H_{k_total} vs.

10   anneal temperature for a bulk nickel iron cobalt (NiFeCo)

film deposited on a tantalum (Ta) layer at various

deposition angles θ. Since the induced magnetic anisotropy

resulting from a nonzero deposition angle is a result of

surface topography either from the magnetic material layer

15   itself or from the tantalum layer (See FIG. 5), the

magnitude and direction of H_k is substantially stable with

temperature so that a thermal drift is minimized. Further,

an H_k of a film deposited at an oblique deposition angle

does not significantly depend on the bit shape.

20   Turning back to FIG. 8, the experiment consists of

applying a magnetic field transverse to the total

anisotropy direction while the film is annealed at each

temperature for approximately 15 minutes. For the film

with pair ordering anisotropy only ($\theta = 0º$), the measured

25   H_{k_total} drops significantly with increasing temperature due

to thermal diffusion of the like pairs of atoms. As θ

increases, the induced anisotropy H_{ki} is due primarily to

surface topography from an angled deposition, so that the

change in anisotropy after anneal is minimized.   A

thermally stable anisotropy is advantageous for an MRAM

5   cell because the repeated application of magnetic fields.

for switching will not significantly alter the switching

field of a memory cell with such a stable anisotropy.

Therefore, a nonzero deposition angle, θ, can be

chosen to obtain the desired anisotropy magnitude and

10   direction for MRAM device 10.   The total anisotropy for a

magnetic layer in device 10 will be approximately

$$H_{k\_total} = H_{k\_shape} \pm H_{k\_pair} \pm H_{ki}(\perp) \pm H_{ki}(||)$$

Thus, by choosing an appropriate deposition angle for

15   a given magnetic layer or underlayer, H_{ki} can be used to

vary H_{k_total}.

Referring back to FIG. 1, it will be understood that

there are several other embodiments of memory device 10

that include at least one layer deposited at a nonzero

20   deposition angle θ.   In a first embodiment, the free layer

(i.e. magnetic region 15) can have at least one layer (i.e.

layers 55, 65, and/or 45) deposited at a nonzero deposition

angle θ.   In this embodiment, the induced anisotropy H_{ki}

will add or subtract to the other anisotropies (i.e. H_{k_shape}

25   or H_{k_pair}) for magnetic region 15.   This will substantially

depend on whether $H_{ki}(||)$ or $H_{ki}(\perp)$ is induced and also on

the orientation of the other anisotropies.

In the first embodiment, the deposition angle θ is small which has the advantage of maintaining uniform film thickness across the wafer. It will be understood that the uniformity could also be improved by depositing

5 approximately one-half the material of a given layer and then rotating the wafer 180° and completing the deposition. The rotation would mitigate the effects of a thickness gradient due to the angled deposition.

In a second embodiment, MRAM device 10 has a

10 substantially circular shape so that the shape anisotropy is minimized. In addition, the magnetic material can be chosen to have a small H_{k_pair} so that H_{ki} is the dominant magnetic anisotropy.

In a third embodiment, seed layer 31 can be deposited

15 at nonzero θ while the subsequent layers are deposited at θ approximately equal to 0°. This embodiment has the advantage of maintaining uniform film thickness across the wafer while still obtaining a substantial H_{ki} from seed layer 31.

20 In a fourth embodiment, magnetic region 17 includes the free layer and magnetic region 15 includes the pinned and fixed layer (an alternative embodiment could have the free layer in magnetic region 15 and the pinned and fixed layer in magnetic region 17). In magnetic region 15, at

25 least one layer (i.e. layers 55, 65, and/or 45) can be deposited at nonzero deposition angle θ. In the fourth

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embodiment, only magnetic region 15 is deposited obliquely

at a large angle θ to induce a large H_{ki} in the pinned and

fixed layers. A large H_k is desirable for the pinned and

fixed layers so that the magnetization direction will be

5   held substantially fixed during writing and reading of

memory device 10. This will substantially minimize any

disturbance from the movement of the magnetization

direction in the pinned and fixed layers.

It will be understood that device 10 can be deposited

10   using an ion beam deposition system, a physical vapor

deposition system, or the like, wherein, in the preferred

embodiment, the portion of device 10 deposited at a nonzero

deposition angle is performed with the substrate static

(non-rotating). To produce a large induced H_{ki} it is

15   desirable to produce a relatively collimated beam of

incident flux material. A collimated beam can usually be

produced within low pressure deposition systems or systems

that have long target to substrate distances.

For an ion beam deposition system, the substrate is

20   oriented at an oblique angle relative to a line drawn from

the center of the beam spot on the sputtering target to the

center of the substrate. However, for a physical vapor

deposition system 110, the substrate can be swept across

the sputtering target, as illustrated in FIG. 6, wherein θ

25   varies as a function of time. In the preferred embodiment,

physical vapor deposition system 110 includes a shaped

target 116 and flux shapers 118. A substrate 112 is

generally held by a rotating table or arm 114 which

receives substrate 112 from a transfer robot (not shown)

through a gate valve (not shown). The basic setup of a

deposition system and the operation of a rotating table or

5   arm in such a system is well known to those skilled in the

art and will not be elaborated upon further here.

Turn now to FIG. 7 which illustrates a side view of

physical vapor deposition system 110. Substrate 112 is

positioned at the angle, θ, relative to a reference line

10   122 by robot arm 114, as illustrated. A plasma (not shown)

is adjacent to target 116 while substrate 112 is moved

along a reference line 120 by arm 114. When the target is

biased with a voltage the plasma sputters the target

material into a wide distribution of angles. Thus, at the

15   beginning of the substrate sweep, when the substrate is off

to one side of the target, the depositing atoms are

predominantly from an oblique angle. The sweep range and

velocity of the substrate can be controlled to determine

how much of the layer is deposited under oblique

20   conditions. One advantage of this method of deposition is

that the deposited film is more uniform while still

obtaining an obliquely deposited film with an induced

magnetic anisotropy from a nonzero deposition angle θ at

the beginning of the layer deposition pass and at the end.

25   The shapers 118 are designed to provide a film of uniform

thickness over the substrate 112 for the desired sweep

range and velocity profile. This method can be used to

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produce layers having a well-defined anisotropy direction even when no magnetic field is applied during deposition of the layer.

Thus, a new and improved method of depositing a
5 material layer for magnetoelectronic devices, such as MRAM devices including MTJ and/or GMR devices, magnetic sensors, etc., which utilize a ferromagnetic layer has been disclosed. The method involves depositing portions of the magnetic device at a nonzero deposition angle. An
10 advantage of this deposition method is that the induced magnetic anisotropy is substantially more stable with temperature. Another advantage is that the range of values for the magnitude of the induced anisotropy is increased. Still another advantage is that the new and improved
15 deposition method produces a well-defined anisotropy axis without need for an applied magnetic field during deposition. Although it will be understood that an applied magnetic field can be used if desired. Further, the nonzero deposition angle can be chosen to supplement or
20 oppose the shape anisotropy, the pair ordering anisotropy, or the intrinsic anisotropy. Also, a sufficiently large induced anisotropy can be used in creating a fixed layer, if desired, so that the antiferromagnetic pinning layer 32 is not needed.

25 Various changes and modifications to the embodiments herein chosen for purposes of illustration will readily occur to those skilled in the art. To the extent that such

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modifications and variations do not depart from the spirit of the invention, they are intended to be included within the scope thereof which is assessed only by a fair interpretation of the following claims.